Operational Snow Modeling at the National Operational Hydrologic Remote Sensing Center

Tom Carroll

National Operational Hydrologic Remote Sensing Center
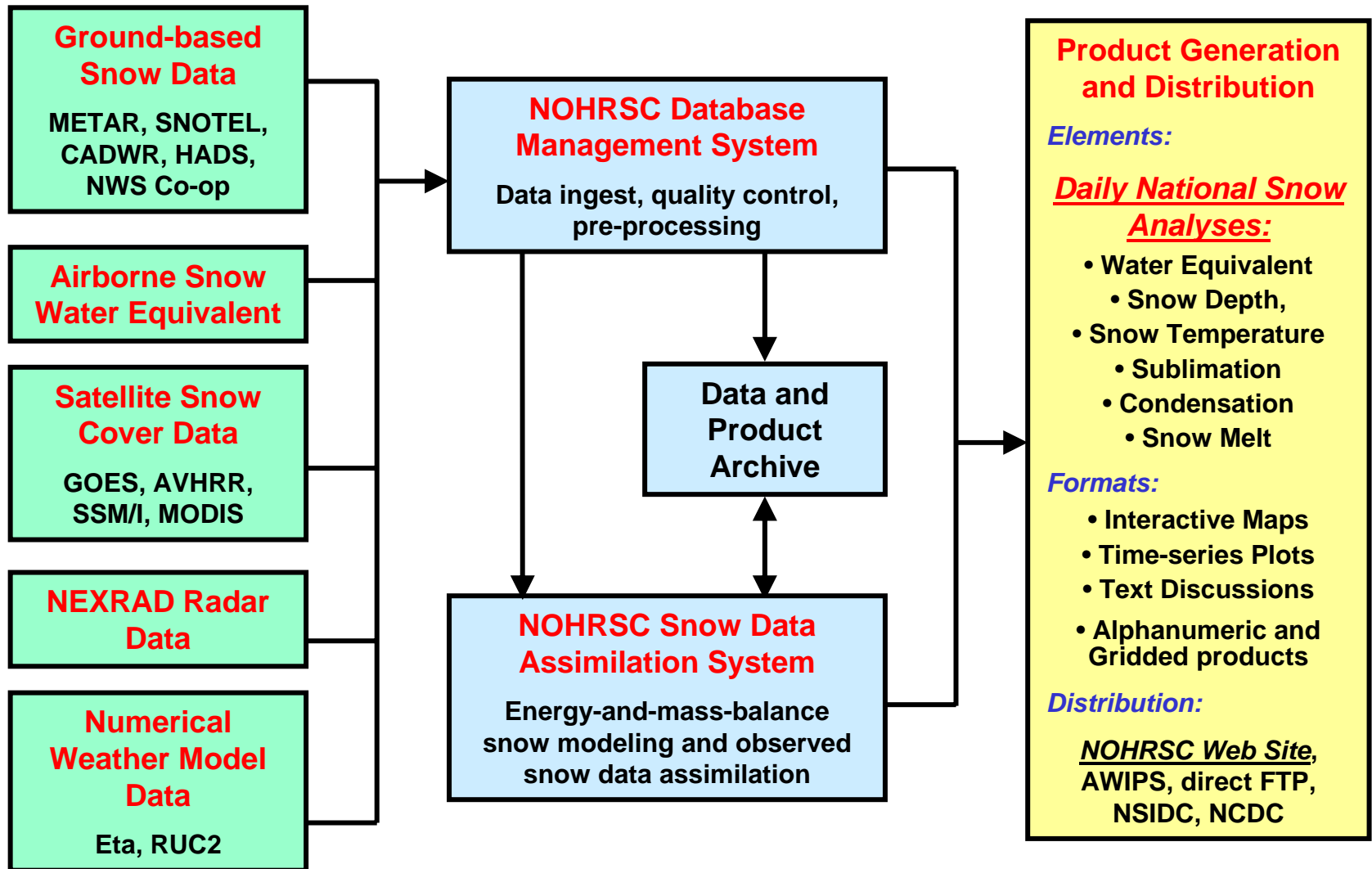
Hydrologic Services Division

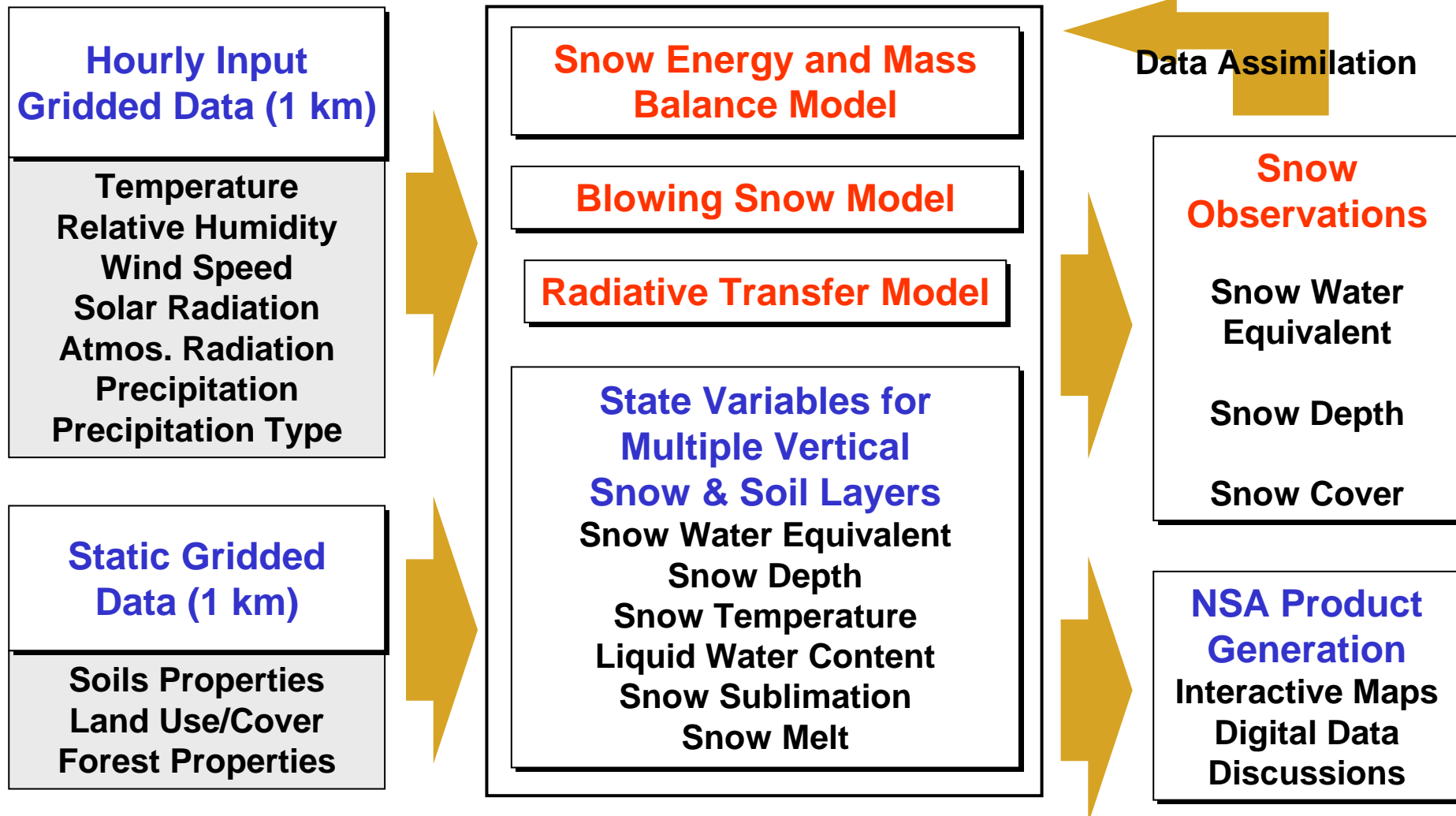*Office of Climate, Water, and Weather Services*

National Weather Service, NOAA
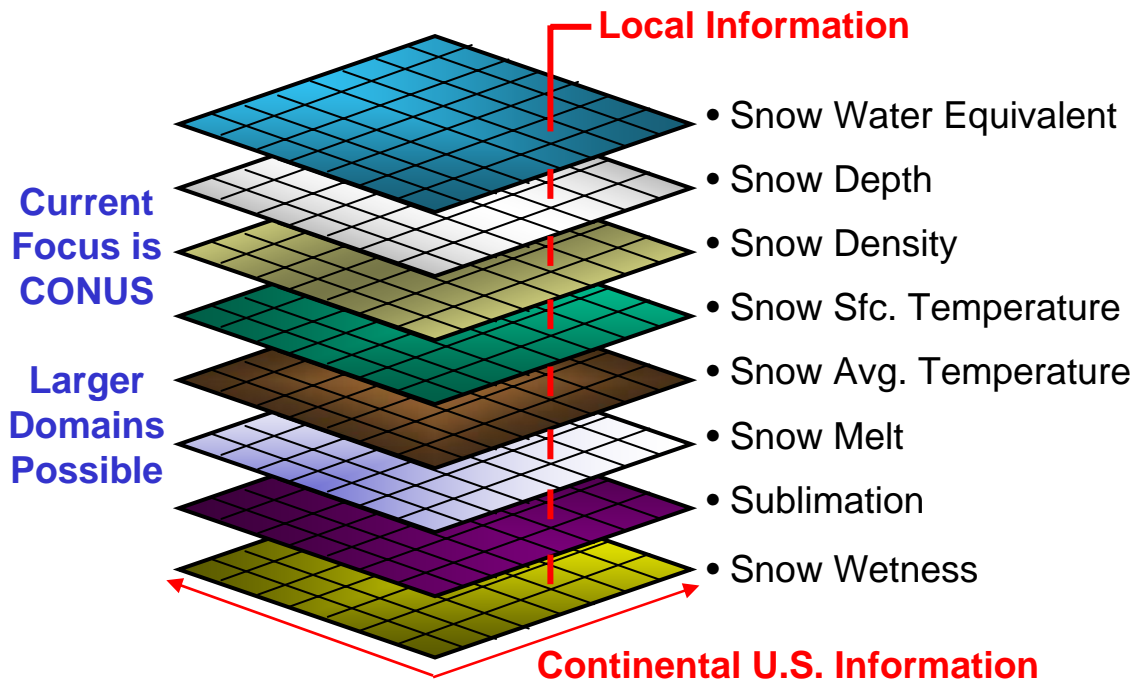
U.S. Department of Commerce

National Operational Hydrologic Remote Sensing Center

NOHRSC

NOHRSC Operations

Ground-based Snow Data

METAR, SNOTEL, CADWR, HADS, NWS Co-op

Airborne Snow Water Equivalent

Satellite Snow Cover Data

GOES, AVHRR, SSM/I, MODIS

NEXRAD Radar Data

Numerical Weather Model Data

Eta, RUC2

NOHRSC Database Management System

Data ingest, quality control, pre-processing

Data and Product Archive

NOHRSC Snow Data Assimilation System

Energy-and-mass-balance snow modeling and observed snow data assimilation

Product Generation and Distribution

Elements:

Daily National Snow Analyses:
- Water Equivalent
- Snow Depth,
- Snow Temperature
- Sublimation
- Condensation
- Snow Melt

Formats:
- Interactive Maps
- Time-series Plots
- Text Discussions
- Alphanumeric and Gridded products

Distribution:

NOHRSC Web Site, AWIPS, direct FTP, NSIDC, NCDC

NOHRSC Snow Data Assimilation System (SNODAS)

Hourly Input Gridded Data (1 km)

Temperature
Relative Humidity
Wind Speed
Solar Radiation
Atmos. Radiation
Precipitation
Precipitation Type

Static Gridded Data (1 km)

Soils Properties
Land Use/Cover
Forest Properties

Snow Energy and Mass Balance Model

Blowing Snow Model

Radiative Transfer Model

State Variables for Multiple Vertical Snow & Soil Layers
Snow Water Equivalent
Snow Depth
Snow Temperature
Liquid Water Content
Snow Sublimation
Snow Melt

Data Assimilation

Snow Observations

Snow Water Equivalent

Snow Depth

Snow Cover

NSA Product Generation
Interactive Maps
Digital Data
Discussions

NOHRSC Integrated Products and Services

High-resolution Gridded Snow Hydrology Products (to NSIDC, NCDC, NDFD)

Local Information

Current Focus is CONUS

Larger Domains Possible

- Snow Water Equivalent
- Snow Depth
- Snow Density
- Snow Sfc. Temperature
- Snow Avg. Temperature
- Snow Melt
- Sublimation
- Snow Wetness

Continental U.S. Information

Applications

Drought

Flood Management

Water supply

Transportation

Emergency Management

Agriculture

Ecosystems Management

Research

Users

NWS

NOAA

Federal Agencies

Tribal Agencies

State Agencies

Private Sector

Public

Academia

Soil moisture and temperature states are also maintained in the NOHRSC model, but there is currently no focus on this capability (e.g. assimilation of soil moisture observations).

NOHRSC Integrated Products and Services

1. **Gridded snowpack properties for the CONUS**

2. **1 km^2 spatial resolution**

3. **1 hour temporal resolution**

4. **Near real-time modeling and assimilation**

5. **Incorporates _all_ relevant information:**

    - **Ground-based snow data (depth and SWE)**

    - **Airborne gamma snow water equivalent**

    - **Satellite areal extent of snow cover**

    - **NWP model forcing fields**

Snow Water Equivalent

NOHRSC California Airborne Flight Lines

NOHRSC California Airborne Flight Lines

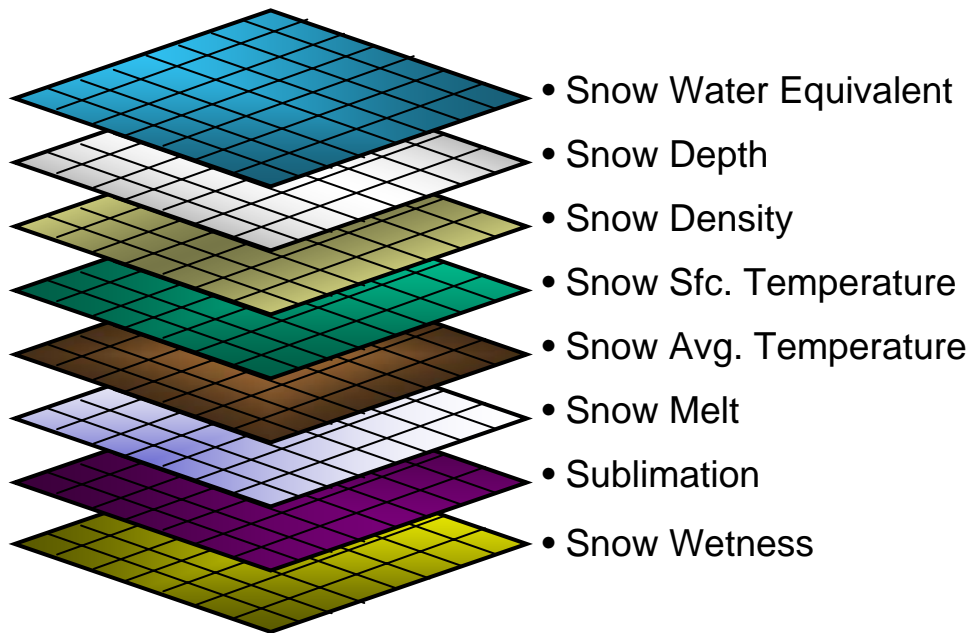1. **Airborne snow water equivalent**

   • **Mean areal integration (~10 km x 300 m)**

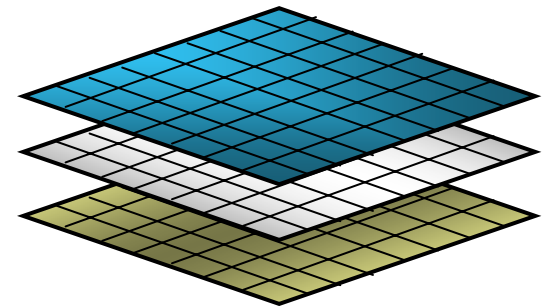2. **Airborne soil moisture**

   • **Mean areal integration (~10 km x 300 m)**

   • **Upper 20 cm of soil**

   • **Percent by weight**

NOHRSC Contribution to HMT

1 km² spatial resolution
1 hour temporal resolution

Input to _distributed_ soil moisture accounting model

- Snow Water Equivalent
- Snow Depth
- Snow Density
- Snow Sfc. Temperature
- Snow Avg. Temperature
- Snow Melt
- Sublimation
- Snow Wetness

Hydrometeorological test-bed domain (American River basin)

Thank you

www.nohrsc.noaa.gov

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National Operational Hydrologic Remote Sensing Center
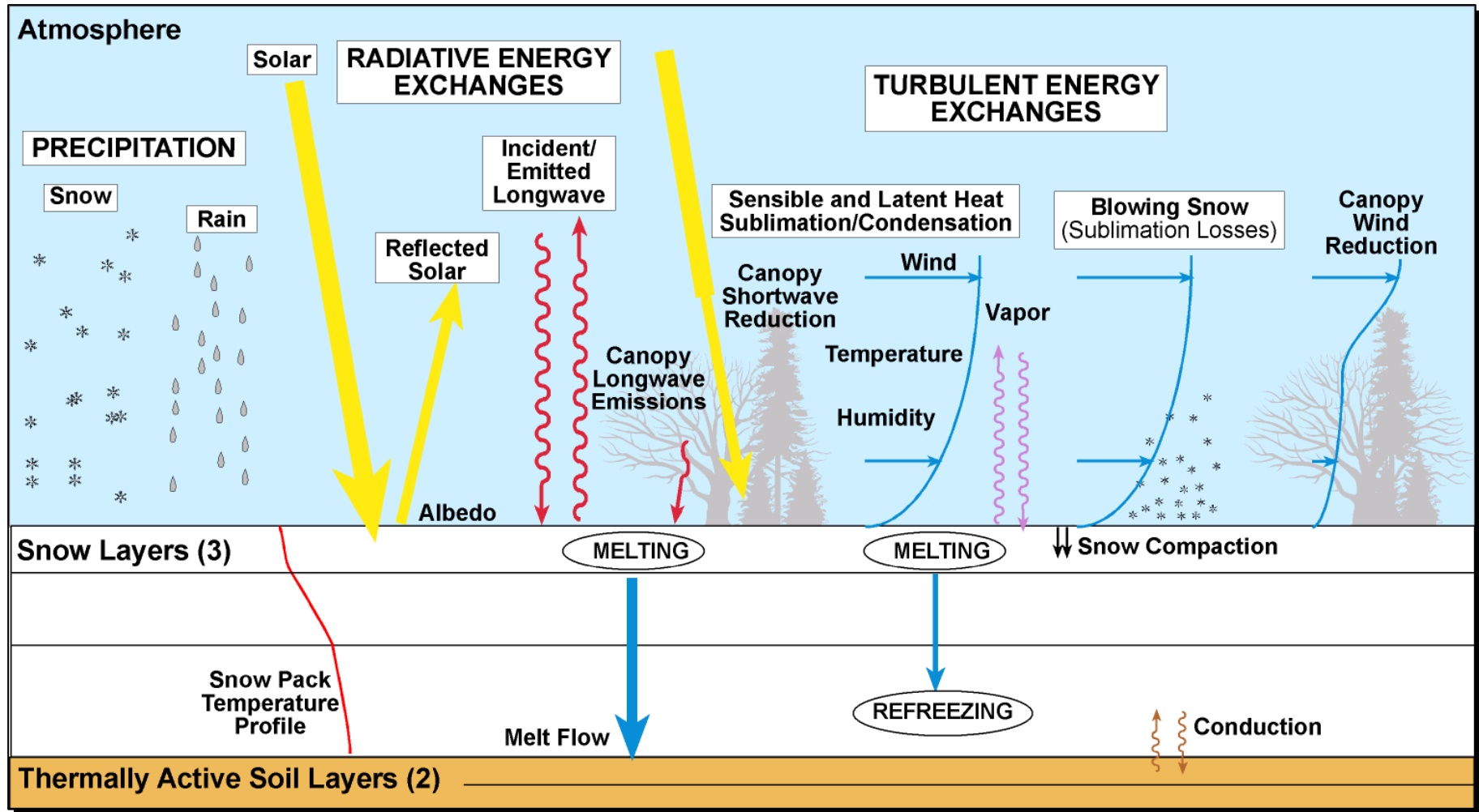
Hydrologic Services Division

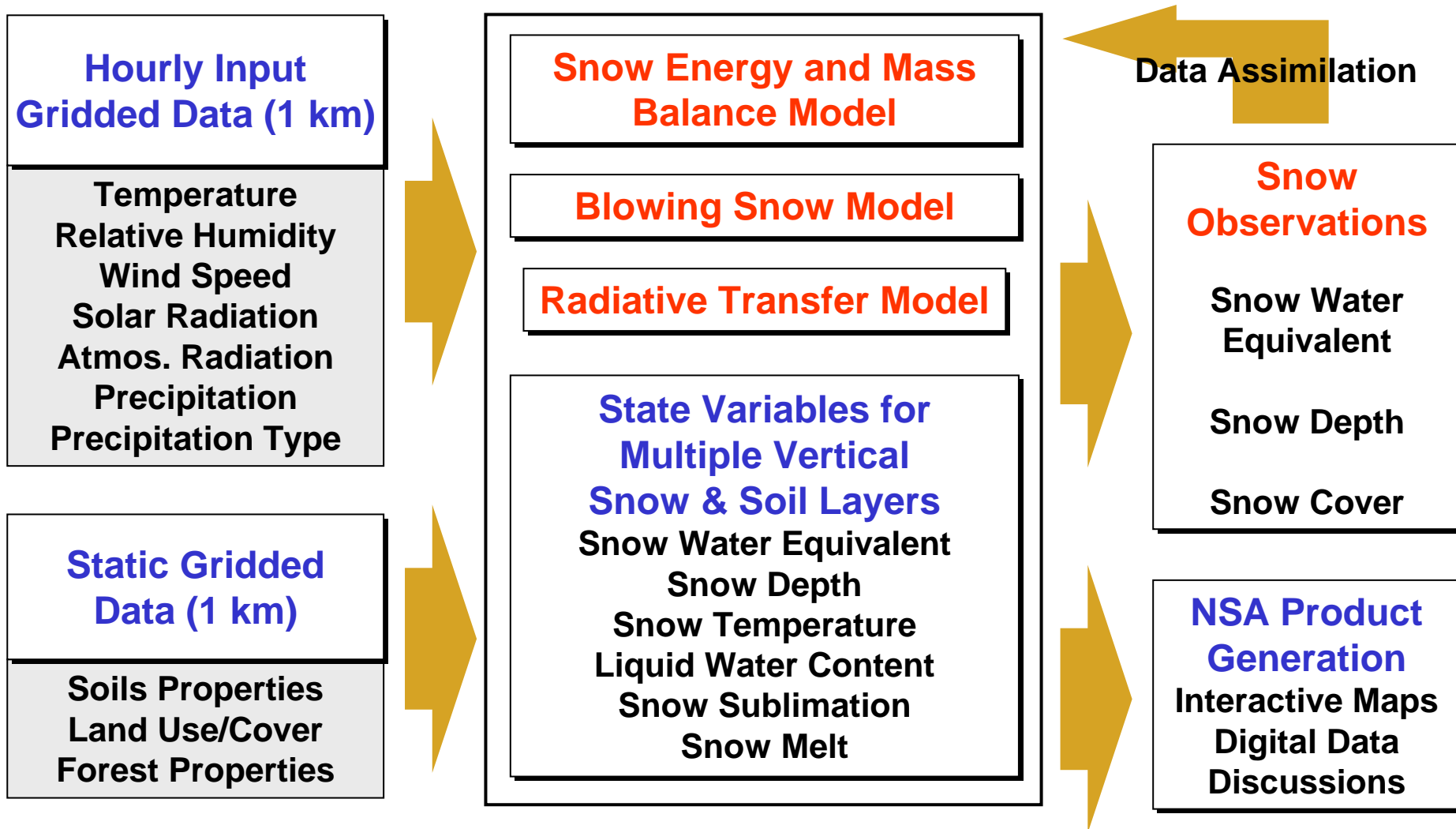*Office of Climate, Water, and Weather Services*
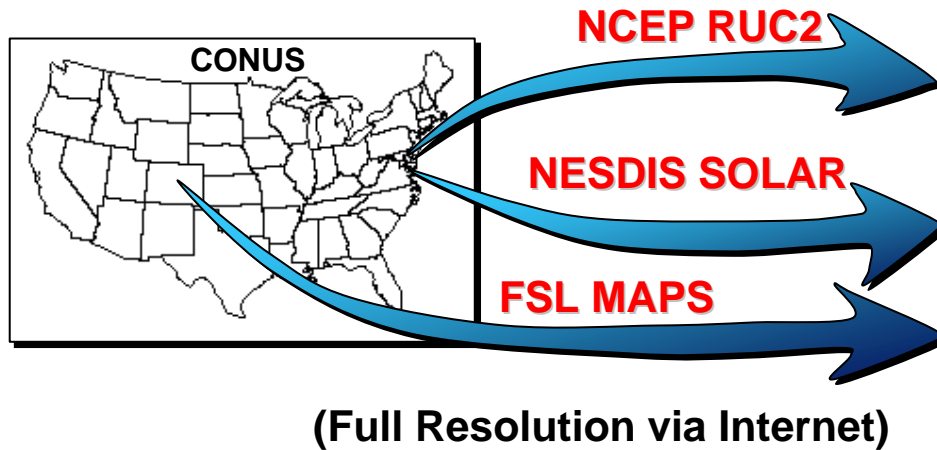
National Weather Service, NOAA

U.S. Department of Commerce

NOHRSC Snow Model Physics

Snow Modeling Framework

Hourly Input Gridded Data (1 km)

Temperature
Relative Humidity
Wind Speed
Solar Radiation
Atmos. Radiation
Precipitation
Precipitation Type

Static Gridded Data (1 km)

Soils Properties
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Data Assimilation

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Snow Water Equivalent

Snow Depth

Snow Cover

NSA Product Generation
Interactive Maps
Digital Data
Discussions

Preprocessing: Forcing Data

CONUS

NCEP RUC2

NESDIS SOLAR

FSL MAPS

(Full Resolution via Internet)

Hourly Mesoscale Input Data

RUC2 Analyses (20 km, 40 levels)
RUC2 12-h Forecasts (20 km, 40 levels)

MAPS Analyses (20 km, 40 levels)
MAPS 12-h Forecasts (20 km, 40 levels)

GOES Two-Stream Solar (0.5°)
(Direct Beam and Diffuse)

Physically Based Downscaling (1 km)

Spatial/Temporal Gap Filling
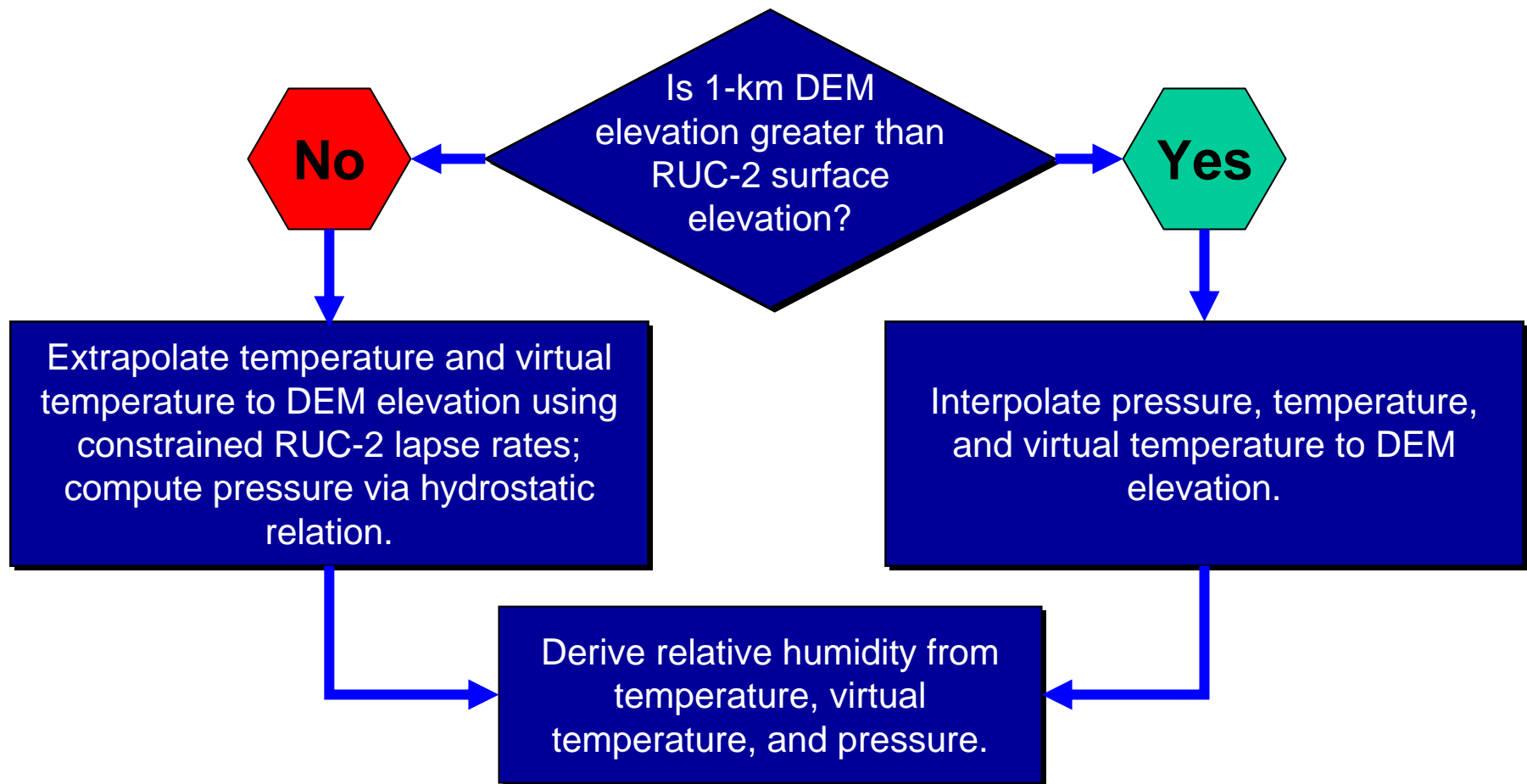
Hourly Snow Model Forcing (1 km)

Surface, Spatially & Temporally Continuous

Air Temperature
Relative Humidity
Wind Speed
Precipitation (Snow)
Precipitation (Non-Snow)
Solar Radiation

Downscaling: Thermodynamic

RUC-2 Multi-level Thermodynamic Variables
(20-km Pressure, Temperature, and Relative Humidity)

Is 1-km DEM elevation greater than RUC-2 surface elevation?

No

Yes

Extrapolate temperature and virtual temperature to DEM elevation using constrained RUC-2 lapse rates; compute pressure via hydrostatic relation.

Interpolate pressure, temperature, and virtual temperature to DEM elevation.

Derive relative humidity from temperature, virtual temperature, and pressure.

Downscaling: Solar Radiation

GOES Two-Stream Solar Radiation
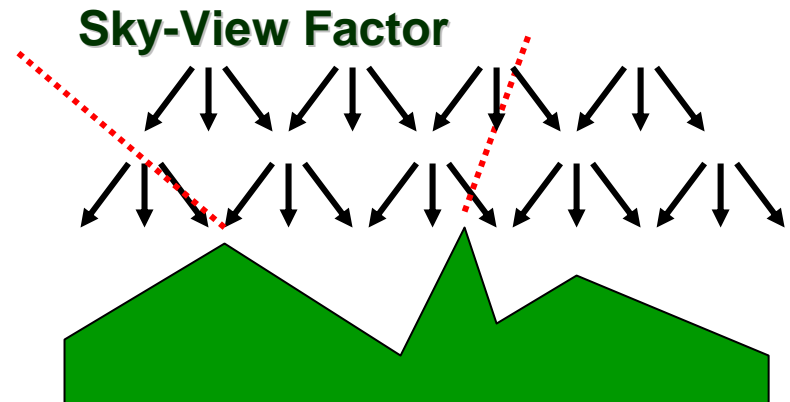### (0.5 degree Direct Beam and Diffuse Irradiance)

Direct Beam Irradiance

Diffuse Irradiance

Sky-View Factor

Terrain Cross-Section
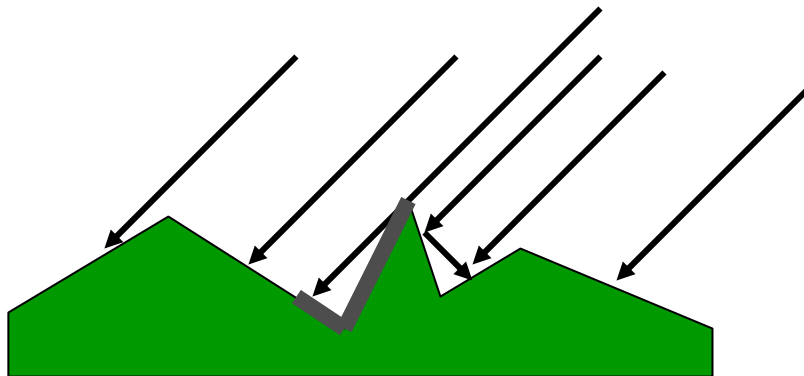
Terrain Cross-Section

- **Terrain Reflection**
- **Topographic Shading**

- **Sky-View Factor**
- **Incidence Angles**

Preprocessing: Gap Filling

Forcing data must be spatially and temporally continuous.

Method 1. Substitution

9Z RUC2
10Z RUC2
11Z RUC2
12Z RUC2
13Z RUC2

10Z RUC2
1-hr
Forecast

or

11Z MAPS

or

10Z MAPS
1-hr
Forecast

Hourly Snow Model Forcing (1 km)

Surface, Spatially & Temporally Continuous

Air Temperature
Relative Humidity
Wind Speed
Precipitation (Snow)
Precipitation (Non-Snow)
Solar Radiation
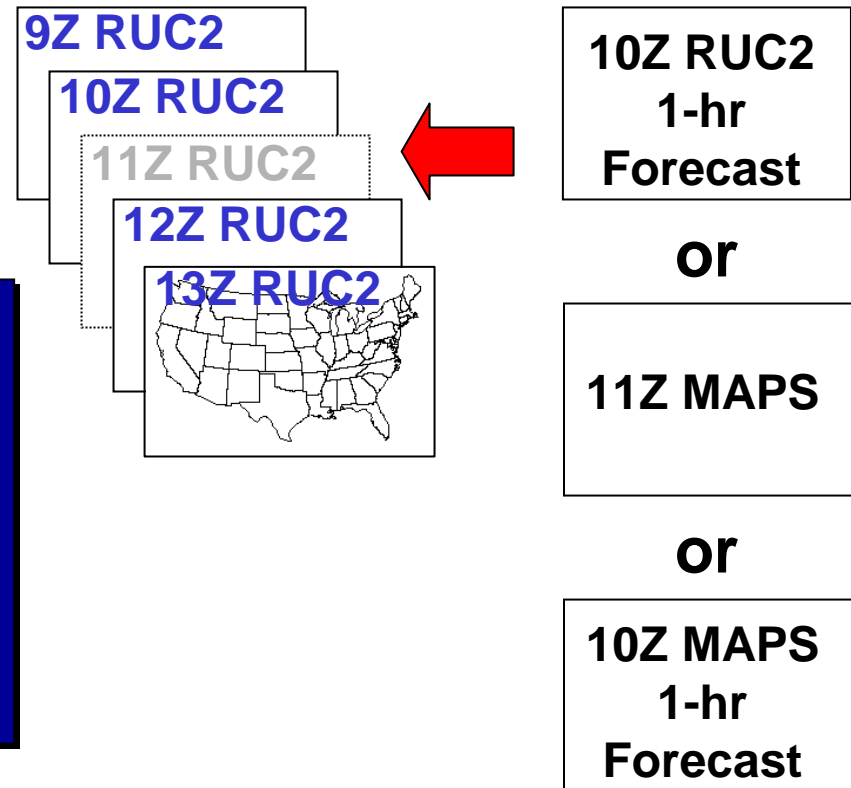
Preprocessing: Gap Filling

Forcing data must be spatially and temporally continuous.

Method 2. Interpolation

9Z RUC2
10Z RUC2
11Z RUC2
12Z RUC2
13Z RUC2

10Z RUC2

12Z RUC2

<div style="background:navy;color:white;">

Hourly Snow Model Forcing (1 km)

Surface, Spatially & Temporally Continuous

Air Temperature
Relative Humidity
Wind Speed
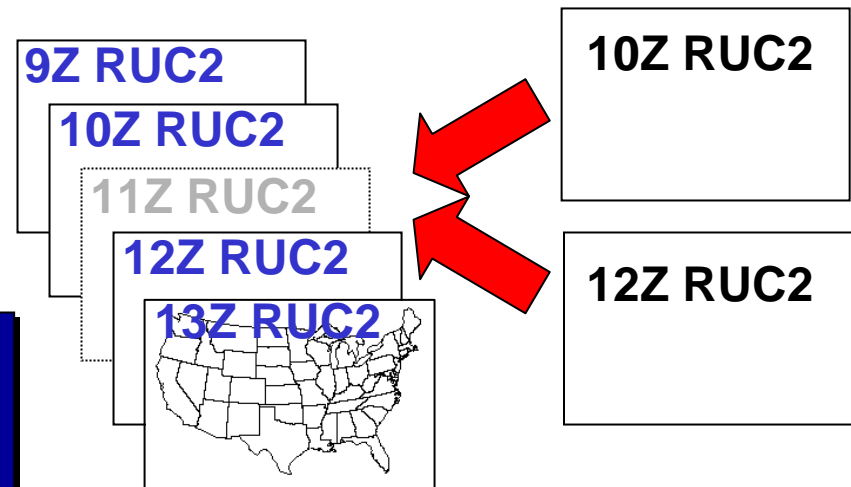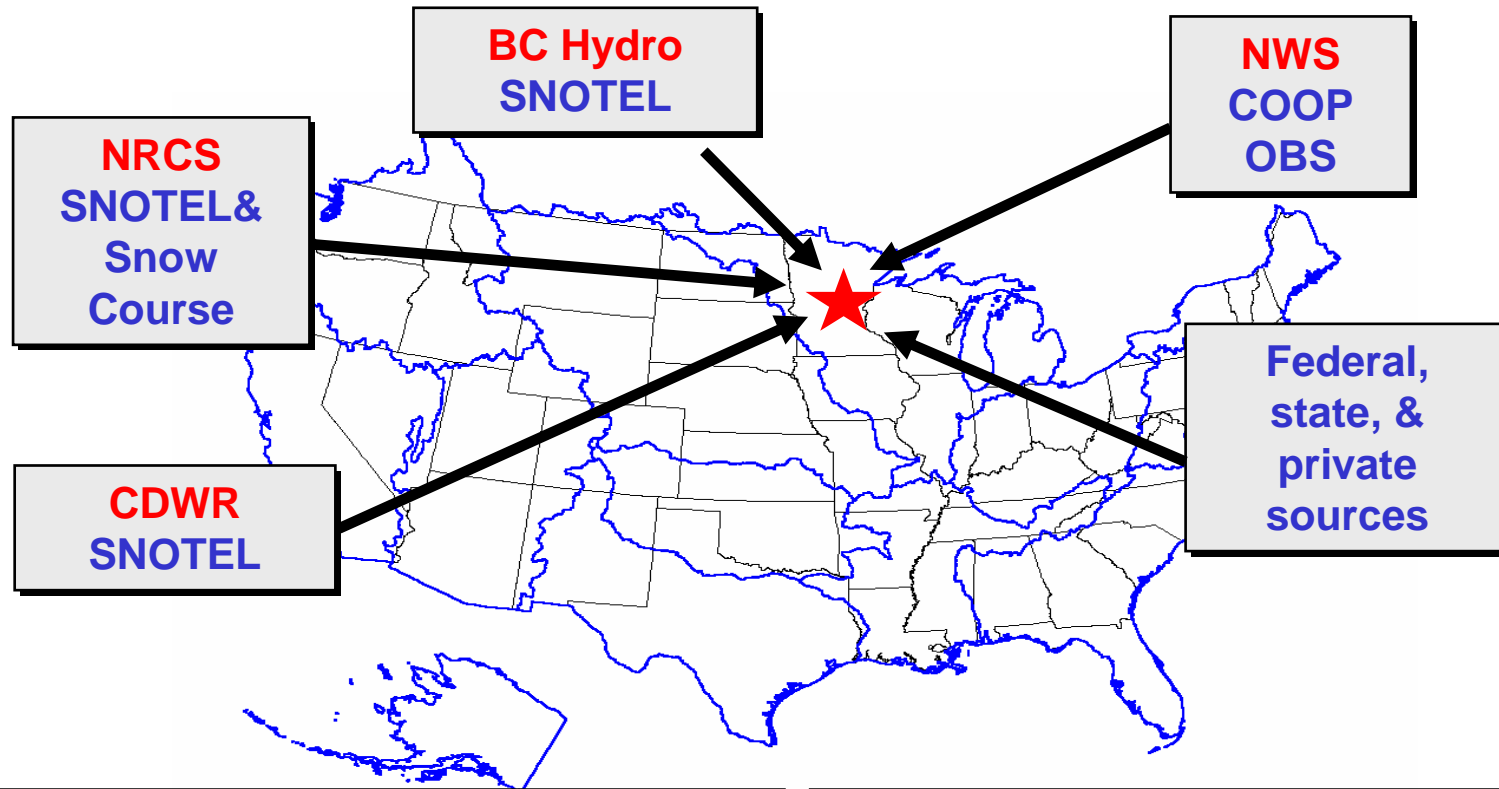Precipitation (Snow)
Precipitation (Non-Snow)
Solar Radiation

</div>

Gap-filling is automated based on user-defined prioritization of methods.

Daily In-situ Snow Observations
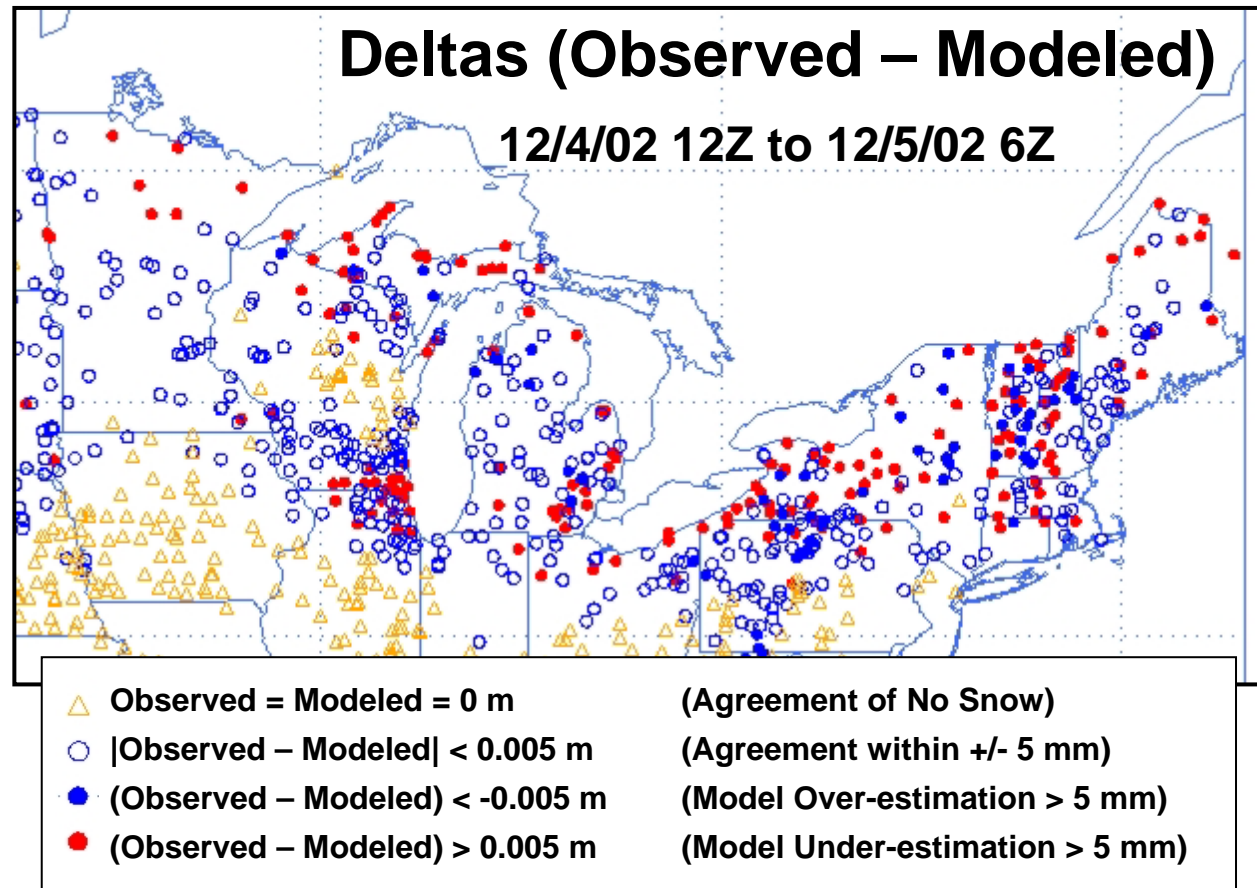

BC Hydro SNOTEL

NRCS SNOTEL& Snow Course

NWS COOP OBS

CDWR SNOTEL

Federal, state, & private sources

Over 20,000 reporting stations are included in analyses

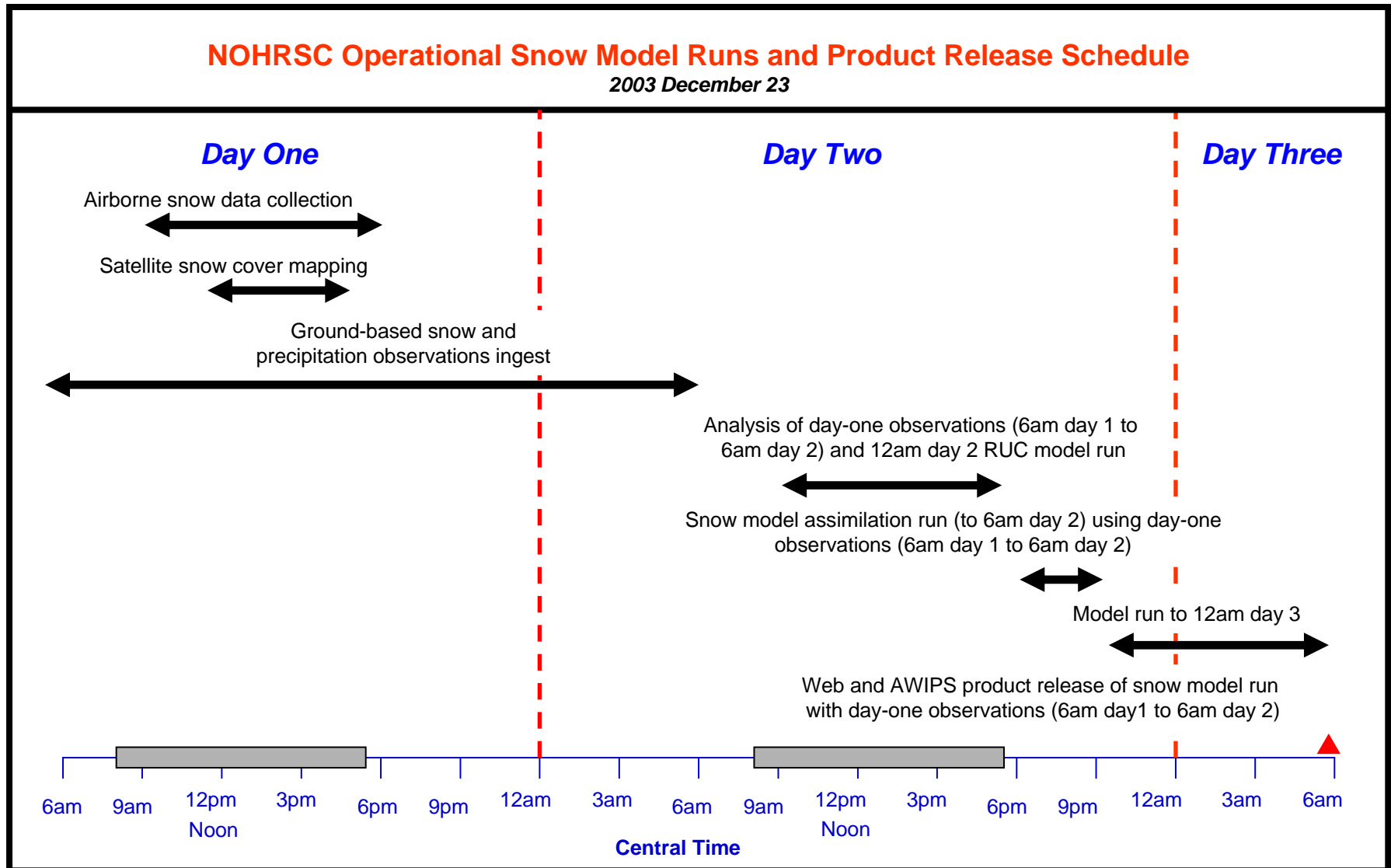**Snow Water Equivalent and/or Snow Depth**

Snow Observation Assimilation

Daily SWE and Snow Depth Observations are used to update the model

- **Deltas between observed and modeled states are examined**
  - *Coherent spatial pattern is required to warrant update*
    - Subgrid variability

- **If pattern is explainable, update field is generated and used to nudge the model toward observed states**

Deltas (Observed – Modeled)

12/4/02 12Z to 12/5/02 6Z

△ Observed = Modeled = 0 m	(Agreement of No Snow)
⬡ |Observed – Modeled| < 0.005 m	(Agreement within +/- 5 mm)
🔵 (Observed – Modeled) < -0.005 m	(Model Over-estimation > 5 mm)
🔴 (Observed – Modeled) > 0.005 m	(Model Under-estimation > 5 mm)

Data Processing Chronology

NOHRSC Operational Snow Model Runs and Product Release Schedule
2003 December 23

Day One   *Day Two*   *Day Three*

Airborne snow data collection

Satellite snow cover mapping

Ground-based snow and
precipitation observations ingest

Analysis of day-one observations (6am day 1 to
6am day 2) and 12am day 2 RUC model run

Snow model assimilation run (to 6am day 2) using day-one
observations (6am day 1 to 6am day 2)

Model run to 12am day 3

Web and AWIPS product release of snow model run
with day-one observations (6am day1 to 6am day 2)

6am   9am   12pm Noon   3pm   6pm   9pm   12am   3am   6am   9am   12pm Noon   3pm   6pm   9pm   12am   3am   6am

Central Time
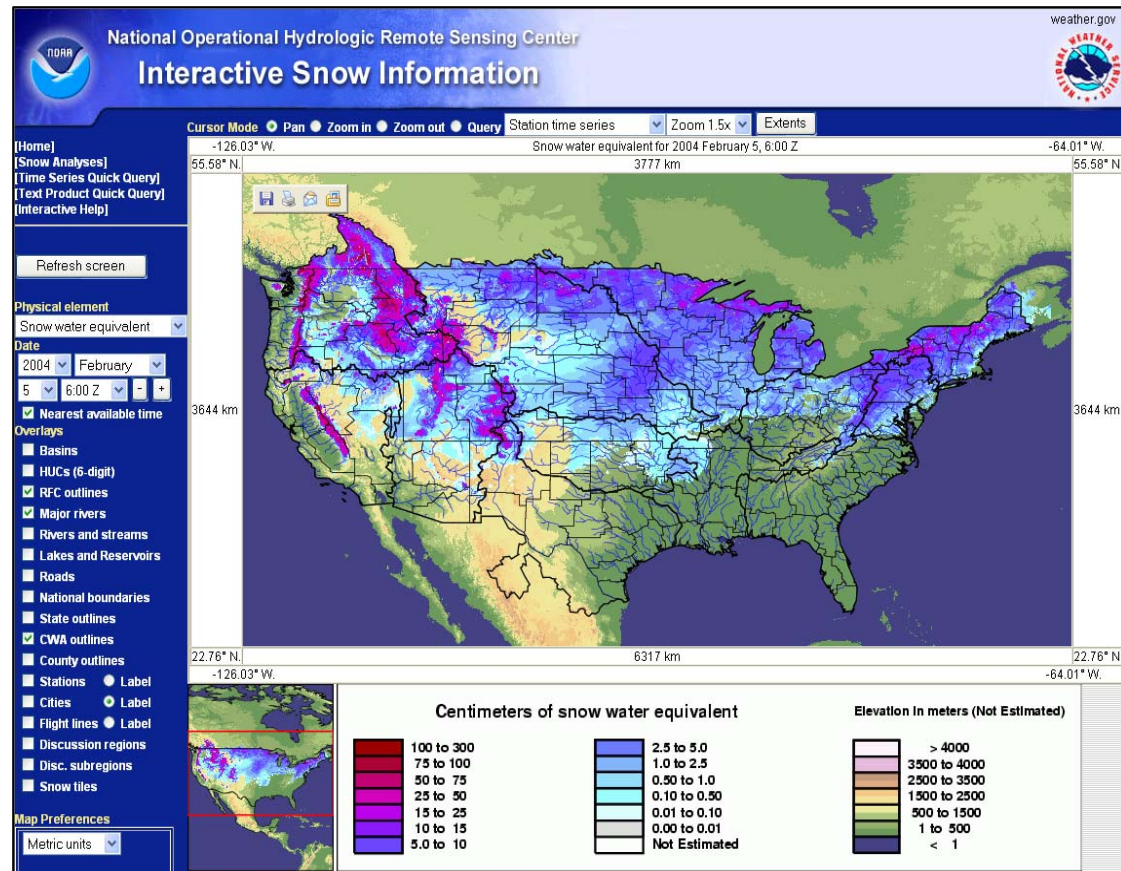
User Interactive Mapping on Internet

- **Comprehensive snow hydrologic information products**
  - *Snow water equivalent, depth, wetness, temperature, melt, sublimation losses*

- **GIS-based interactive information distribution on the Internet**
  - *Overlay administrative and basin boundaries, rivers, roads, cities*
  - *Zoom to full 1-km resolution*
  - *Query stations for time-series history*
  - *Export text data summaries for each basin*

- **Up to 300,000 hits a day during peak season**

User Interactive Mapping on Internet
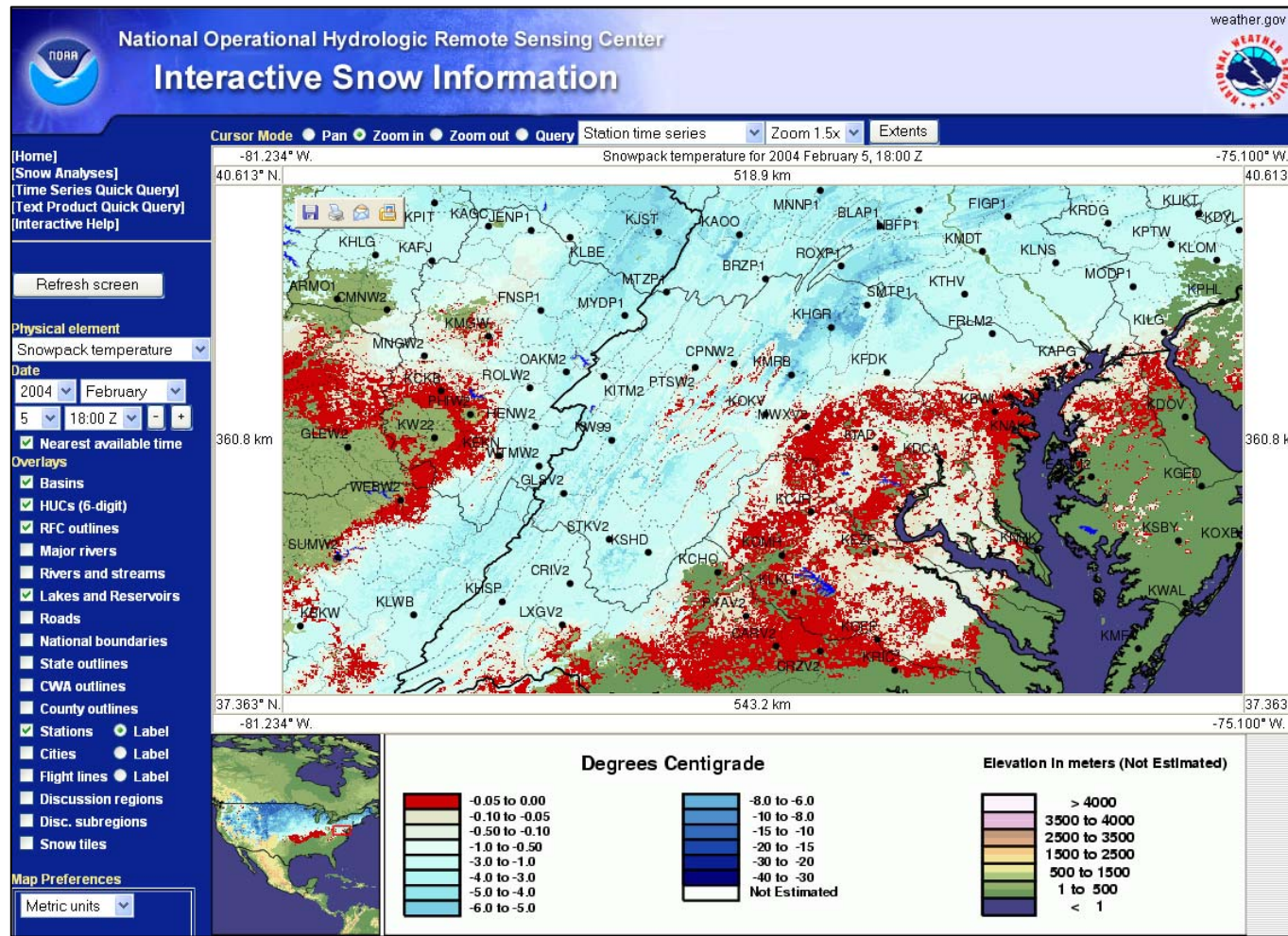
Full-Res Zoom

- *Snow Temperature*
  - *Feb 5, 2004 18Z*
- *Red shows areas where snow is estimated to be at or near melting point*
- *Blue shows areas where snow is estimated to be colder than –1C*
- *NWS basin outlines shown in dashed lines*
- *Stations that report snow observations are shown*
  - *Stations can be queried for time series history at location*

Guidance and Diagnostics

- *Maps of snowpack variables besides water content are valuable to forecasters*
  - *Aid in understanding snow conditions, where snowmelt is likely to occur*

Time Series History Queries on Internet

User can query any of 40,000 stations shown on interactive map.
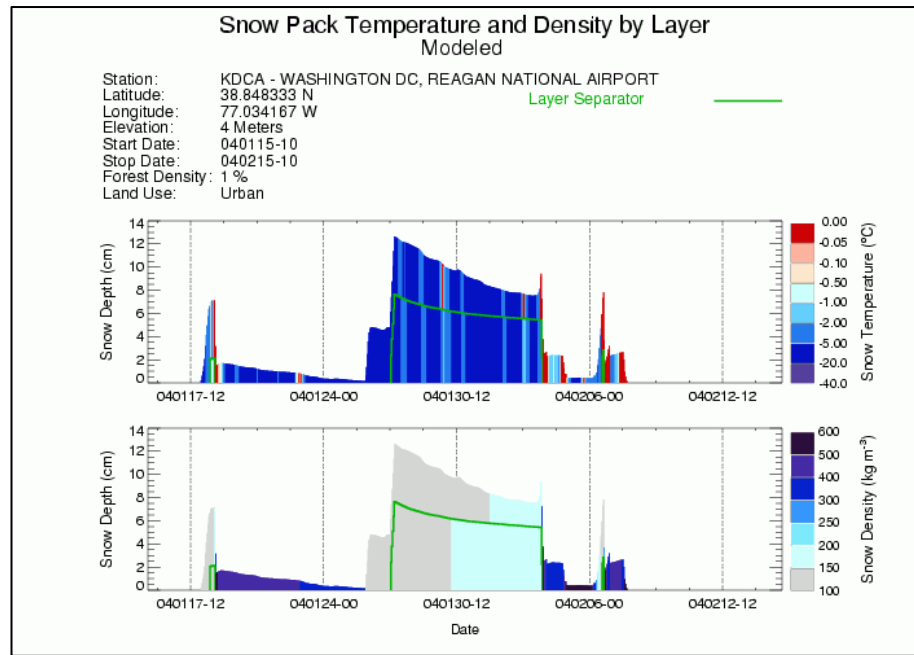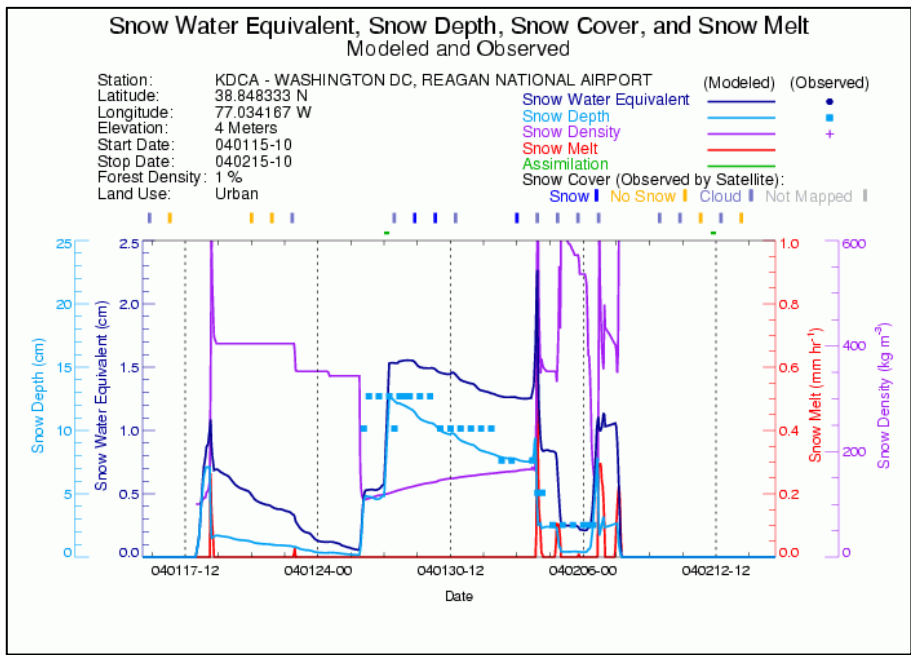
- **SWE, Depth, Density, and Melt**
  - *e.g. Washington DC (Reagan National Airport)*
    - *Jan 15 - Feb 15, 2004*
  - *Dark blue line show modeled SWE*
  - *Light blue line shows modeled snow depth*
  - *Light blue points show observed snow depth*
  - *Assimilation of observed snow depth on Jan 27 corrected for underestimated snow precipitation*

- **Vertical Profile of Temperature, Density**
  - *Same location and time period*
  - *Snow remained relatively cold for 6-7 days following second storm*
  - *Rainfall on Feb 4 contributed to rapid warming of the snowpack, followed by melt*
  - *A smaller rain and snow event occurred on Feb 6*
  - *Gradual densification due to snow compaction*